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Oil Shales in Montana

Richard N. Miller

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A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of

Bachelor of Science

in

Geological Engineering

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INTRODUCTION

Montana has long been known to have very large resources of coal and oil, and undetermined amounts of oil shale. The reserves of coal and oil have been proven, in part, and have been produced commercially, but not much is known about the extent and apparent value of the oil shales. Under present conditions, and according to standards set by the United States Bureau of Mines, the shales are not of commercial value. They are, however, a potentially valuable mineral resource, and portions of them will possibly be utilized, although not in the near future.

The findings of all previous investigations are included in this paper, as well as information on six new localities assayed by the author. This new quantitative data supplements and substantiates the previous work.

The author wishes to acknowledge the very able assistance given him by Dr. Eugene S. Perry, who outlined the initial work, and by Dr. Oliver D. Blake and Professor Forbes S. Robertson, who further outlined procedures and constructively criticized this report. Acknowledgement is given also to Dr. Edwin G. Koch and Professor J. G. Ruggles of the Chemistry Department, and to Professor D. D. McGlashen of the Mineral Dressing Department, all of whom made available laboratory space and equipment, and who gave advice on certain techniques which greatly facilitated the laboratory work. The author also wishes to acknowledge Mr. James H. Clement, of the Shell Oil Company in Billings, Montana, who made available certain shale samples, thereby furthering considerably the scope of the paper.

GENERAL TECHNOLOGY OF OIL SHALE

The term "oil shale", as it is most generally used, covers a wide variety of laminated, lithified mixtures of argillaceous sediments, and a substance, or substances, termed "kerogen", the word being derived from two Greek words meaning "producer of wax". Not all oil shales have been formed in the same manner, or have included in them kerogen of the same chemical composition, nor is the kerogen of any particular shale a definite chemical compound. All oil shales, however, have the common property of yielding shale oil when destructively distilled, and it has been shown that the abundance of kerogen in a given bed is a direct measure of the oil yielding capacity of the bed. Thus kerogen is undoubtedly the source of the oils obtained by retorting an oil shale.

Many oil shales from the world over have been examined microscopically, and a conclusion drawn, that generally kerogen is composed of minute carbonized plant fragments, such as small spores and pollen; yellow or reddish-yellow spherical bodies, which are regarded as algae, spores, spore cases, grains of resin, or globules of oil; and irregular streaks of reddish-yellow, dark brown, or opaque material, any of the last of which have not been further classified. Shells of small crustaceans, and parts of the skeletons and scales of fish have also been observed in a number of shales, and might possibly add to the crude shale oil recoverable. (10,p 35).

Kerogen is, for all practical purposes, insoluble in the common organic solvents, such as carbon disulphide, and is therefore classed as a pyrobitumen or asphaltic-pyrobitumen, depending upon the particular chemistry involved in its large and extremely complex molecules. Asphaltic-pyrobitumen on being heated decomposes into bitumen, and thus becomes soluble in organic solvents. Little is known about this chemical change, but it has been suggested that it may be one of complete or partial depolymerization, the conversion apparently progressing at temperatures as low as 200° C.. If the kerogen in a particular shale is of the asphaltic-pyrobitumen type, the production of crude shale oil is preceded by two distinct conversions, (1) the decomposition of the kerogen into a bitumen, and (2) the conversion of this first-formed bitumen into gas, oil vapor, and carbon. If the kerogen is of the non-asphaltic type, it is possible that no conversion into bitumen takes place when the shale is retorted. In this case, the pyrobitumen decomposes directly into gas, oil vapor, and carbon. (10, p 45).

This breakdown of complex organic molecules into ones of a more simple nature, through application of heat, is often termed destructive distillation, pyrolysis. The oils thus produced from kerogen are apparently mixtures of members of the paraffin, olefin, diolefin, and naphthene series, and their derivatives, with some of the aromatics and acetylene series present also. It has been found that these oils have boiling points ranging from less than 50° C., to more than 400° C., and specific gravities of less than 0.7, to over 1.0. When oil shales are retorted, permanent or fixed gases are also produced. These gases are chiefly carbon monoxide, carbon dioxide, hydrogen, hydrogen sulphide, and the lower members of the various hydrocarbon series, with those of the paraffin and olefin series predominating. (10, p 46).

A fact to be emphasized is that the properties of the crude shale oil, and therefore of its ultimate refinery products, are greatly influenced by the complexity of the kerogen molecules, and by the conditions under which the oil is produced. In the laboratory, it is soon evident, that unless an efficient means of controlling the heat is available, no two distillations proceed in the same manner. This fact has bearing on the quantity and quality of the crude shale oil thus produced.

Winchester (32), in 1928, made an extensive study of the oil shales of the United States. Much of his work was concerned with the Tertiary oil shales of the Rocky Mountain Region. Before making any estimates as to reserves, and value of reserves, he compiled a set of standards with which to evaluate oil shale properties. Taken into consideration were the remoteness of the shales from market, and the probable cost of mining. No shale was considered mineable if it was less than a foot thick, or if it would yield less than 15 gallons of oil to the ton, or less than 3000 barrels of shale oil per acre of shale property. On this basis, in 1928, a shale stratum four feet thick and yielding 15 gallons of oil per ton of shale, or a stratum one foot thick yielding 60 gallons of oil per ton was mineable. (11, p 4). These standards do not apply to conditions as they exist today, but will serve as something with which the Montana oil shales can be compared.

GEOLOGICAL OCCURRENCE

Oil shales have been observed at five horizons in the Montana geologic column, none of which are at all persistent throughout the state. Apparently conditions favorable for the formation of oil shale were present only in local and possibly isolated areas. An interesting fact, however, is that Montana has been exposed five times to a bituminous shale type of deposition. One of these, the basal Lodgepole, has fauna known to be correlative with black shales of the Mississippi Valley and Mid-Continent area.

The petroliferous beds will be discussed only briefly where the oil shale possibilities are nil, but in some detail where the shales are at their best. The reader is referred to Figure 1, page 6 of this paper, which will serve to illustrate stratigraphically the major occurrences in the state, and to Figure 2, page 7, which will show the areas in which the major oil shales are known to cropout, and thus where they have been sampled.

Tertiary Oil Shales

These oil shales (lignites?), which occur in the southwestern part of the state in the vicinity of Dillon, lie in long narrow basins, and are generally of limited extent. The shales are interbedded with sandstones, sandy shales, and true lignites. These beds may be more nearly lignitic shales, rather than true oil shales. They are mentioned in this paper for the sake of completeness, and because they are capable of yielding oil when destructively distilled, as do the true oil shales. (10, p 24).

STRATIGRAPHIC OCCURRENCE OF MONTANA OIL SHALES

FORMATION				THICKNESS	DESCRIPTION
QUATERNARY					
TERTIARY				—	(OIL SHALE OR LOW GRADE LIGNITE)
CRETACEOUS	UPPER	MONTANA GROUP			
CRETACEOUS	UPPER	COLORADO GROUP	MOWRY		COLORADO SHALE
CRETACEOUS	UPPER	COLORADO GROUP	THERMOPOLIS	1800	UPPER--DARK MARINE SHALE, WITH COMPACT BITUMINOUS SHALE AND THIN MALTHA BEARING LS AT BASE. LOWER 610-700 BLACKLEAF MBR ALT CONG & BIT SHALE.
CRETACEOUS	LOWER				
JURASSIC					
TRIASSIC					
PERMIAN	PHOSPHORIA	E			
PERMIAN	PHOSPHORIA	D		56	INTERBEDDED PETROLIFEROUS SHALES THIN LIMESTONES, AND PHOSPHATE ROCK.
PERMIAN	PHOSPHORIA	C			
PERMIAN	PHOSPHORIA	B			
PERMIAN	PHOSPHORIA	A			
PENNSYLVANIAN					
	BIG SNOWY GROUP	HEATH		600	INTERBEDDED GRAY SHALE, BLACK FISSILE SHALE, MASSIVE BRN SANDSTONES, AND MINOR GRY TO BLK LIMESTONES.
	BIG SNOWY GROUP	OTTER			
	BIG SNOWY GROUP	KIBBEY			
	BIG SNOWY GROUP	CHARLES			
MISSISSIPPIAN	MISSION CANYON				
MISSISSIPPIAN	LODGEPOLE	WOODHURST			
MISSISSIPPIAN	LODGEPOLE	PAINE		20	THIN BEDDED DENSE LIMESTONES, CALCAREOUS SH AND SHALY LIMESTONES. BASAL 20' CONODONT BEARING FISSILE BLACK SHALE.
DEVONIAN					
ORDOVICAN					
CAMBRIAN					

FIGURE I-- STRATIGRAPHIC OCCURRENCE

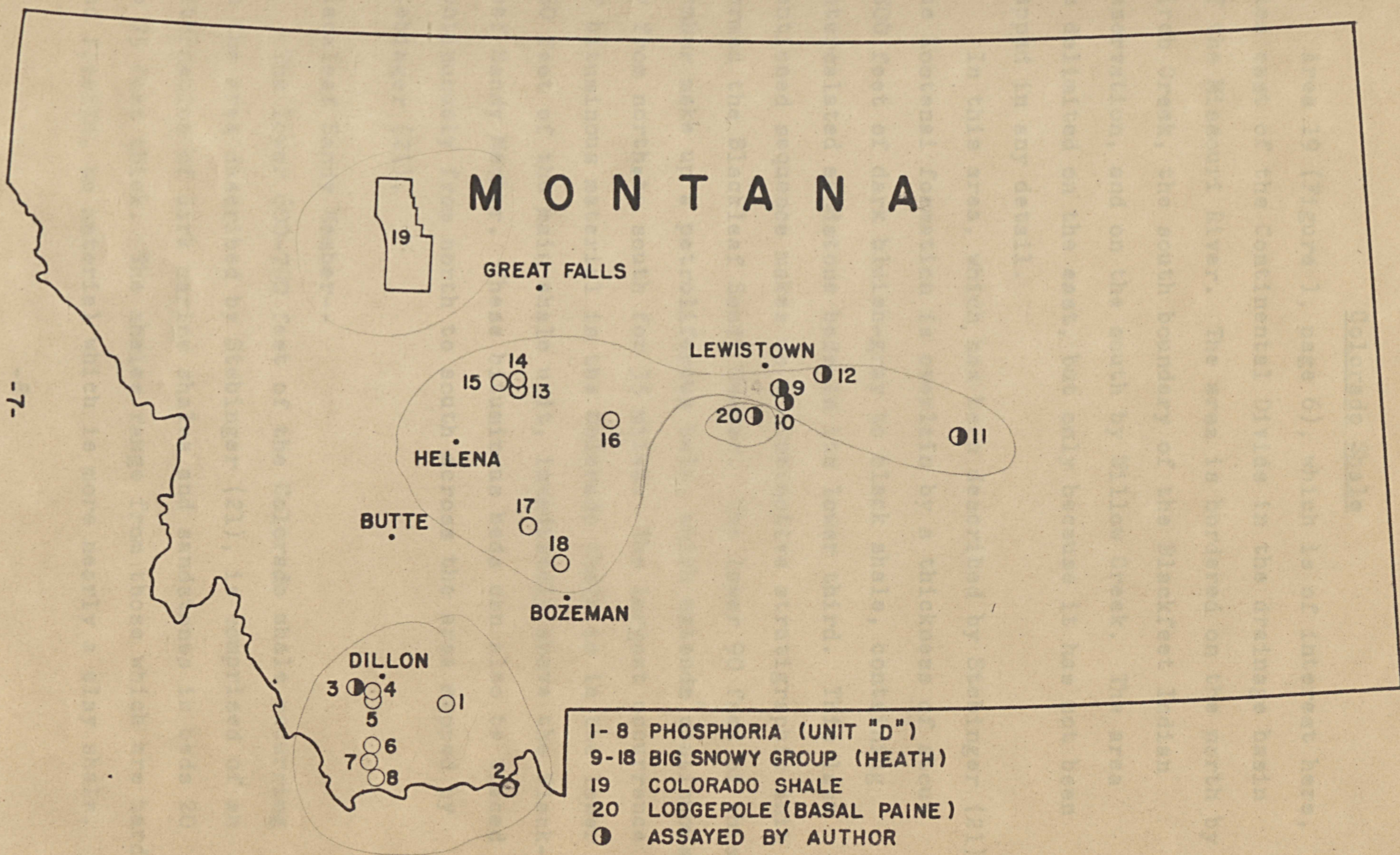


FIGURE 2-- A MAP OF MONTANA SHOWING WHERE MAJOR SHALE OCCURRENCES HAVE BEEN SAMPLED AND ASSAYED

Colorado Shale

Area 19 (Figure 1, page 6), which is of interest here, lies east of the Continental Divide in the drainage basin of the Missouri River. The area is bordered on the north by Birch Creek, the south boundary of the Blackfeet Indian Reservation, and on the south by Willow Creek. The area is delimited on the east, but only because it has not been mapped in any detail.

In this area, which has been described by Stebinger (21), the Kootenai formation is overlain by a thickness of about 1800 feet of dark bluish-gray to black shale, containing intercalated sandstone beds in its lower third. This last mentioned sequence makes up a distinctive stratigraphic unit termed the Blackleaf Sandy Member. The lower 90 feet of this member make up a petroliferous belt, which extends continuously from north to south for 35 miles. The largest occurrence of bituminous material in the Colorado shale is in the lower 150 feet of the main shale unit, immediately above the Blackleaf Sandy Member. These bituminous beds can also be traced continuously from north to south across the area mapped by Stebinger (21).

Blackleaf Sandy Member--

The lower 600-700 feet of the Colorado shale occurring in the area described by Stebinger (21), is comprised of an alternation of dark marine shales and sandstones in beds 20 to 75 feet thick. The shales range from those which are hard and fissile, to material which is more nearly a clay shale.

The sandstones are gray to greenish-gray in color, and are medium to coarse grained. These sandy beds are rather evenly distributed throughout the Blackleaf member, the lower 90 feet of which is composed in part of compact bituminous shale, which fractures conchoidally, and which emits a transient odor of kerosene on the fresh break. The only exposures of this Blackleaf member are in a disturbed belt along the western margin of the area. The petroliferous unit comprises a continuous belt 35 miles long, extending from north to south across the area between Deep Creek, in section 18, T. 27 N., R. 8 W., and the Sun River, in section 29, T. 22 N., R. 8 W.. (21, p 158).

Shale Above the Blackleaf Sandy Member--

The only important occurrence of bituminous material in the Colorado shale is in the lower 150 feet of the main shale unit, just above the Blackleaf Sandy Member. These petroliferous beds are thought to have an average thickness of 50 feet throughout the area. They consist of compact black bituminous shale containing thin beds of impure limestone, the addiative thickness of which does not exceed 12 feet. The greater part of the shale in the upper portion of the Colorado is fairly compact, and bluish-gray on dry outcrops. Smaller amounts of bituminous shale are present in this sequence also. Except where covered by surficial deposits, the folded beds of the upper Colorado shale come to the surface in a practically continuous belt of outcrops extending from Birch Creek on the north, to Willow Creek on the south.(21, p 161).

Phosphoria Formation

In Montana, and possibly in the immediately adjacent states, the Phosphoria formation is seen to cropout along the slopes of many of the chief mountain ranges, the petroliferous portion, however, is limited to the extreme southwestern corner of the state (Figure 2, page 7). The stratigraphy of the Phosphoria formation has been worked out in detail by Swanson (22) and others, and has been found broadly divisible into five relatively distinct units, these being assigned letters A, B, C, D, and E, in progressing up the column from older into younger strata.

The major petroliferous occurrence is limited to the "D" unit of the formation. This unit is generally termed the "upper phosphatic shale zone", and consists of mudstones, petroliferous mudstones, phosphate rock, and thin beds of limestone. The colors range from light-gray to medium-gray and grayish-black. In the Dell-Dillon area of southwestern Montana, this petroliferous and phosphatic unit is overlain by a sequence of cherty and non-cherty mudstones and siltstones, termed the "upper siliceous member", unit "E", and is underlain by the "upper siliceous and carbonate member", unit "C", which is comprised of interbedded chert, sandstone, and carbonate rock in massive beds 2 to 4 feet thick.

The upper phosphatic shale member will be described in some detail below, the greatest attention being paid the section at Daly's Spur near Dell, Montana, as it was one of the sequences sampled and assayed by the author.

Daly's Spur Area--

This occurrence (Location 3, Figure 2, page 7) is on the west side of the U.S. Highway 91 in section 36, T. 8 S., R. 10 W., a few miles south of Dell, Montana. The upper phosphatic shale zone (Figure 3, page 12) occurs in a north trending homocline, which has been deeply eroded and partly buried by early Tertiary conglomerates and lavas. The unit is exposed for about a mile along the highway, between Grasshopper Creek and Daly's Spur, where it attains a thickness of 56 feet with a zone of phosphate rock from 4 to 13 feet above the base. (14, p 6). Figure 4, page 12, is a view looking directly at the upper phosphatic shale member, close to the section measured by Lowell (22, p 25-26m) which appears below. This measured sequence lies in section 36, T. 8 S., R. 10 W., which is approximately the section sampled and assayed by the author. These strata strike north to N 30° E and dip 30-40° to the west.

Upper Siliceous Member (Unit "E")-- 136'

Upper Phosphatic Shale Member (Unit "D")-- 54.5'

Rock Description	Thickness
mudstone- - - - - - - - - - - - - - - - - - - -	1.0
mudstone- - - - - - - - - - - - - - - - - - - -	1.3
mudstone- - - - - - - - - - - - - - - - - - - -	1.4
phosphate rock, argillaceous - - - - - --	0.8
mudstone, phosphatic- - - - - - - - - - -	0.7
phosphate rock, argillaceous- - - - - -	0.3
mudstone, phosphatic- - - - - - - - - - -	1.2
phosphate rock, phosphatic mudstone- - -	1.5
mudstone, calcareous- - - - - - - - - - -	0.9
phosphate rock, argillaceous- - - - - -	0.5
mudstone, phosphatic- - - - - - - - - - -	0.5
mudstone- - - - - - - - - - - - - - - - - - - -	0.4
phosphate rock, argillaceous- - - - - -	0.4
mudstone, calcareous- - - - - - - - - - -	0.3
phosphate rock, argillaceous- - - - - -	0.3

Figure 3-- A view, looking northwest, of the Phosphoria formation as it occurs at Daly's Spur near Dell, Montana.

Figure 4-- A closeup of the occurrence in Figure 3, looking directly at unit "D", and the contacts of the overlying and underlying units.

Lowell's section continued (22, p 25-26m)

mudstone, calcareous	4.0
mudstone, calcareous	5.0
mudstone, calcareous	0.8
mudstone, calcareous	2.1
mudstone, calcareous	1.6
mudstone, calcareous	2.7
mudstone, calcareous	1.2
mudstone, calcareous	1.2
mudstone, calcareous	1.6
mudstone, calcareous	0.8
mudstone	1.7
mudstone, calcareous	1.2
phosphate rock	0.3
mudstone, calcareous	0.8
phosphate rock	1.2
mudstone, calcareous	1.4
phosphate rock, argillaceous	1.7
limestone	0.9
mudstone, calcareous	0.8
phosphate rock, argillaceous	0.5
mudstone, phosphate rock	1.3
phosphate rock, argillaceous	1.3
mudstone, calcareous	0.5
mudstone and phosphate rock	1.5
mudstone	1.0
phosphate rock, argillaceous	1.6
phosphate rock, argillaceous (gypsum)	1.4
mudstone, phosphate rock, (gypsum)	0.9
mudstone	0.8
mudstone, phosphatic	1.2
	54.5

Section measured by Lowell (22, p 25-26m)

Upper Siliceous and Carbonate Member (Unit "C")-- 200'

Small Horn Canyon Area--

In this area (Locations 4 and 5, Figure 2, page 7), in sections 14 and 15, T. 9 S., R. 9 W., the upper phosphatic shale member can be traced by outcrop and topographic expression for at least 5 miles on the flanks of the Small Horn Canyon anticline and the Sheep Creek syncline. The lithology here is similar to that at Daly's Spur. (14, p 6).

The Dell Area--

The upper phosphatic shale zone can be traced by outcrop, shale float, and topographic expression for more than five miles in the Dell area of Montana. Here the unit is 83 feet thick, and contains a phosphate zone from 5 to 11 feet above the base. (14, p 7).

The Cedar Creek Area--

Lowell (14) observed only one thin phosphatic shale zone, and that immediately below the upper siliceous member in sections 13-36, T. 9 S., R. 11 W., and sections 1-4, and 10-12, T. 10 S., R. 11 W.. (14, p 7).

Heath Shale

In the Big Snowy and Little Belt Mountains of central Montana, the Heath formation (Locations 9 to 19, Figure 2, page 7) is characterized in the outcrop by an abundance of fissile black shales, which are intercalated with gray shales, massive brown sandstones, and minor gray to black limestones. The sandstones are three in number, and occur in the upper half of the formation. On the southeast flank of the Big Snowy Mountains these are called the Van Dusen Sands, and on the northeast flank the Tyler Sands. The formation has at its immediate base a characteristic black petroliferous shale, which is fossiliferous and conodont-bearing. (17, p 1028).

The Heath formation (Figure 5, page 15) conformably

Figure 5-- A typical occurrence of lower Heath shale, fifteen miles south of Lewistown, Montana

underlies the Amsden in all areas where it occurs, except in a few localities where the latter has been removed by post-Mississippian and pre-Jurassic erosion. "Within a very short distance of the Belt and Big Snowy Mountains, in the general vicinity of the Sweetgrass Arch, the Ellis formation rests successively on Amsden, Big Snowy, and finally Madison sediments." (15, p 1303). At Heath, Montana, south of Lewistown, the Ellis (upper-Jurassic) rests on the conodont zone of the basal Heath.

"The Heath retains its lithology, in progressing in an eastward direction in wells in central North Dakota, the black shale persisting from top to bottom. The thickness of the Heath appears to be the greatest along the axis of the basin, being 625 feet plus in the Little Belt Mountains." (15, p 1304).

The type section of the Heath formation, measured by Scott (17), is situated on the north flank of the Big Snowy Mountains in section 6, T. 12. N., R. 20 E. This measured section, which is tabulated below, and which is in one of the areas sampled by the author (Location 10, Figure 2, page 7), is primarily comprised of black shales, the total thickness of the section being approximately 500 feet.

Amsden formation

Heath Type Section measured by Scott (17, p 1024-1025)

Calcareous black shale, ostracods, Chonetes, Productus, Composita, Trepospira - - - - - - - - - -	5
Black impure limestone, clay and limestone of about equal proportions - - - - - - --- - - - -	1
Calcareous shale, black- - - - - - - - - - - - - - - - - -	4
Calcareous shale -	1
Black petroliferous shale, fish scales rate - - - -	29

Heath Type Section continued (17, p 1024-1025)

Brown sandstone -	12
Black carbonaceous shale - - - - - - - - - - - - - - - -	29
Cross-bedded sandstone, with plant fragments - -	16
Black shale -	68
Black shale, partly covered - - - - - - - - - - - - -	43
Massive sandstone - - - - - - - - - - - - - - - - - - -	27
Covered -	54
Conglomerate and sandstone- - - - - - - - - - - - -	7
Dark shale, partly covered- - - - - - - - - - - - - -	10
Gray limestone -	12
Carbonaceous shale, conodont zone; calcareous concretions filled with Leiorhynchus carboniferum; brachiopods filled with amber oil - -	65
	422

Otter formation

Paine Shale (Basal Lodgepole)

Wherever the base of the Lodgepole formation is exposed, in central Montana, it is marked by an occurrence of conodont-bearing black shales. This black shale makes up the basal part of the Paine formation, and attains a thickness of about 20 feet in central Montana. In this same locality, the upper part of the Paine formation is seen to consist of yellowish and light-green calcareous shale.

To the author's knowledge, the basal Paine shale has not heretofore been studied with the thought in mind that it might be petroliferous. Only one sample (Location 20, Figure 2, page 7) was available for assaying, and it possibly is not representative of the entire formation. This one sample, however, was found to be slightly petroliferous; it is not to be taken as indicative of the nature of the entire black shale sequence.

PREVIOUS WORK

With the exception of the Paine shale occurrence, all of the major oil shale horizons have been sampled and assayed, some in greater detail than others, with more being known concerning the Phosphoria formation than all of the others. Throughout the literature concerned with Montana stratigraphy, there can be seen references made to bituminous shales. Generally the information is limited to a possibly inaccurate figure of the yield.

An attempt is here made to tabulate this information, which is quite extensive for the Phosphoria formation and only scanty for some of the others. The author's data, however small, is reserved for a later section. These descriptions will be listed in order of their apparent importance. The reader is again referred to Figure 2, page 7, for the approximate locations of the major sections.

Phosphoria Formation, Sections and Yields

The data listed below refers to only the "D" unit of the Phosphoria formation, the petroliferous portion of which is limited generally to the extreme southwestern portion of the state. All of the below information is taken from Condit (4, p 24,25,26).

Locality	Character	Thickness	Yield
Location (1), Warm Springs Creek, sec. 15, T. 9 S., R. 3 W.	Phosphate rock, black, oolitic	1'-8"	____
	Clay	5"	____
	Shale, black	1'-8"	3 gal/ton
	Shale, sandy, brown	-----	-----

Locality	Character	Thickness	Yield
Location (2), Idaho-Montana state line, 4 miles southwest of Mount Sautelle section 16, T. 14 N., R. 42 E.	Cherty shale	8'-0"	-----
	Shale, black, bony	4'-0"	6 gal/ton
	Phosphate rock, gray argillaceous	8"	-----
	Sandstone and shale	-----	-----
Location (3), Daly's Spur, Oregon short line R.R., section 2, T. 9 S., R. 10 W. old coal prospect tunnel.	Shale, cherty, phosphatic	9'-0"	-----
	Shale, dark brown, bony	4'-8"	14 gal/ton
	Phosphate rock, dark oolitic, interbedded with oolitic shale	4'-7"	-----
	Shale, black bony	14'-0"	17 gal/ton
	Shale, brownish-gray	1'-0"	-----
	Shale, dark brown, bony	10'-0"	-----
	Lower strata not exposed		
Location (4), Small Horn Canyon, Section 14, T. 9 S., R. 9 S. Dillon Oil Co. property, old coal prospect tunnel.	Roof of bony black shale	-----	-----
	Shale, hard, bony, black	5'-6"	21 gal/ton
	Argillite, soft, phosphatic	5"	17 gal/ton
	Shale, bony	7"	
	Argillite, soft, phosphatic	7"	
	Shale, bony	1'-8"	
	Phosphate rock, gray oolitic	3"	
	Shale, dark	9"	
	Phosphate rock, gray oolitic, shaly	1'-4"	
	Shale, dark	7"	
	Phosphate rock, shaly oolitic	9"	
	Shale, black, soft	1'-2"	
	Phosphate rock, gray oolitic	4"	
	Shale, dark with thin oolitic bands to floor of mine	4'-2"	
Location (5), Divide at head of Smallhorn Canyon, section 23, T. 9 S., R. 9 W., prospect trench	Quartzitic sandstone and chert	50' ±	-----
	Shale, dark bony in lower part	10'-0"	trace
	Shale, black, with 3 layers of phosphate rock 4" thick each	5'-0"	4 gal/ton

Locality	Character	Thickness	Yield
Location (5) continued,	Shale, black tough	11'-0"	15 gal/ton
	Phosphate rock, with three black shaly layers	5'-6"	2 gal/ton
	Shale, brownish-gray, phosphatic	10'-0"	trace
	Shale, brownish-gray, slightly phosphatic	6'-0"	trace
	Sandstone	-----	-----
Location (6), Dry Canyon, near Dell, Montana, section 12, T. 13 S., R. 10 W. prospect trench	Shale, black, top not exposed	1' +	-----
	Phosphate rock, oolitic	1'-0"	-----
	Shale, black, soft, greatly slickensided	8'-0"	17 gal/ton
	Shale, brownish-black	10'-0"	2 gal/ton
	Limestone	8"	-----
	Shale, sandy, brown	6' +	-----
Location (8), Little Sheep Creek, section 4, T. 15 S., R. 9 W., prospect pit dug for coal	Shale, bony, black, with limestone concretions	14'-0"	16 gal/ton
	Clay shale, hard, gritty	2'-6"	
	Shale, black bony,	4'-0"	12 gal/ton
	Phosphate rock, gray oolitic	1'-6"	
	Shale, hard, black	2'-6"	
	Rocks not exposed	8'-0"	
	Limestone, unmeasured	-----	

The Heath Shale, Locations, Geology, and Yield

The black shales of the Heath formation have been prospected for coal and oil shale from a point in Meagher County, Montana, 9 miles south of Adell Post Office, to a point in the Bridger Range close to Bozeman, Montana. Shales have been investigated at several other localities also, but the amount of oil recovered has been insignificant. Information, but this vague and generally inadequate, is available concerning the Heath shale in the Big Snowy Mountains, the literature being old and none too accurate.

The shale occurrences with which we are concerned here, are depicted by sample sites 13 to 17, Figure 2, page 7, the particular data being taken from Condit (4, p 17,18).

Nine miles south of Adell Post Office, Meagher County, Montana; landslide exposure at the head of Freeman Creek on the F.C. Campbell ranch, near line between sections 28-33, T. 14 N., R. 2 E.--2 to 4 gallons of oil per ton of shale (Location (13)).

Location (14), east 1/2 of section 32, T. 14 N., R. 2 E., near the head of the central branch of the north fork of Freeman Creek. 30 feet of shale exposed - petroliferous. Beds anticlinal in nature, complicated with minor fold.--7 to 19 gallons of oil per ton of shale.

Location (15), west fork of Crooked Creek, in section 36, T. 14 N., R. 1 E., same horizon as in Freeman Creek. Crest of an anticline. Thickness 30 to 70 feet. The axis of the anticline trends east-west. The beds dip steeply to the north and south on the flanks.--8 gallons of oil per ton of shale.

Location (16), North Fork of Musselshell River, 4 miles east of Delpine in T. 9 N., R. 11 E. Black fossiliferous shale, lower Heath, seven feet thick. Beds overturned and dip steeply westward.--oil none.

Location (17), 1/2 mile northwest of Lombard Station, Northern Pacific Railroad, Missouri River Valley, T. 4 N., R. 2 E. Black shale and shaly limestone. Petroliferous.--oil none.

Location (18), west side of Ross Peak, Bridger Range, in T. 2 N., R. 6 E. Black shale, probable Heath.--oil none.

The Colorado Shale, Locations, Geology, and Yield

In the area described by Stebinger (21), the petroliferous beds have a thickness probably averaging 50 feet. These rocks occur within area 19, Figure 2, page 7.

The northernmost exposure of these "oil-showings" was found by Stebinger, on the south side of the middle fork of Dupuyer Creek, in section 18, T. 27 N., R. 8 W. The Colorado occurs in extensively crumpled and faulted beds, 10 feet of which are highly bituminous. Some of the interbedded fine-grained limestones contain coatings of tar on fracture surfaces, with more found here than at any other locality. (21, p 162). The southernmost extent of the bituminous beds was found by Stebinger in the Sun River Canal, in section 29, T. 22 N., R. 8 W.. In this locality the structure is complex, and the exact stratigraphic position unknown. This occurrence possibly represents low-grade bituminous beds in the lower portion of the Blackleaf Sandy Member. Typically, the rocks are compact bituminous shales, which fracture conchoidally. Intercalated with the bituminous shale are a few thin maltha-bearing limestones or limey shales. Five samples of this bituminous shale were assayed by D. E. Winchester, of the United States Geological Survey. The shale yielded only one or two gallons of oil to the ton, and can therefore be considered only slightly petroliferous. (21, p 164).

<u>The Tertiary Oil Shales; Locations, Geology, and Yield</u>

The Tertiary oil shales, which are restricted to the southwestern part of Montana, lie in long narrow basins, none of which are of very large extent. The shales occur at approximately the middle of the Tertiary beds, are light brown on fresh surfaces, and break into thin flexible laminae when sufficiently weathered. The shales do not have a characteristic petroliferous odor when freshly broken, but will ignite when exposed to a hot flame. Much of the material, however, is lignitic, and as such can not be classed as true oil shale. This occurrence is tabulated herein for the sake of completeness, and because the material will yield oil when distilled.

The information listed below is after Condit (4, p 28).

Locality	Character	Thickness	Yield
Near Grant, section 6, T. 10 S., R. 12W.	Shale, lignitic, bony Sandstone Shale, lignitic, bony	1'-10" 2'-0" 1'-10"	composite sample 3 gal/ton
Swartz Creek, section 16, T. 11 S., R.12 W.	Shale, sandy Shale, bony, brown Clay shale	6'-0" 3'-6" -----	----- 1 gal/ton -----
Medicine Lodge Creek, section 2, T. 12 S., R. 12 W.	Coal, lignitic, bony Clay shale, sandy Coal, bony, lignitic	3'-0" 40'-0" 1'-0"	1 gal/ton ----- -----
Keystone Creek section 2, T. 12 S., R. 12 W coal prospect	Coal Clay Coal Clay, sandy Coal, bony Clay	1'-0" 3" 10" 3'-8" 2'-1" 4'-0"	----- ----- 36 gal/ton ----- ----- -----
About 500 feet NE of coal prospect pit of above	Shale, sepia brown, weathers to flexible layers	3'-0"	11 gal/ton
Keystone Creek section 3, T. 12 S., R.12W. coal prospect	Coal, lignitic, bony Clay Coal, lignitic, bony Clay Coal, shaly Clay Coal, shaly Clay	1'-4" 3" 6" 6" 2'-1" 1" 2'-8" -----	composite sample 4 gal/ton
Muddy Creek Basin, section 17, T. 13S., R. 10 W., outcrop sample	Sandstone Shale, brown to black, with thin clay bands Beds not well exposed Shale, brown Shale, sepia brown Clay shale Shale, black sandy	----- 10'-0" 60'-0" 3'-4" 2'-1" ----- 7'-0"	----- ----- ----- 4 gal/ton 24 gal/ton ----- 4 gal/ton

Shale Samples Taken from Miscellaneous Sections

Several other sections have been sampled, and are included here as they are possibly of doubtful age and might correspond to the lower Lodgepole occurrence. This last information is taken from Condit (4).

Bottom of small ravine 4 miles N 20° W of Logan, Montana, in T. 2 N., R. 2 E. Soft dark brown shale, 3 feet thick, dipping 40° N. Separated from massive limestone by 30 feet of shale and sandstone. No oil.

West side of Ross Peak, Bridger Range, T. 2 N., R. 6 E., elevation 7700 feet. Section below.

Madison limestone--thin platy layers
Three Forks formation
Shale, black, tough, emits oil odor when freshly broken - 2'-6" (1 gal/ton)
Sandstone, shaley, calcareous, and fossiliferous 30'-0"
Shale, black, emits oil odor when freshly broken 10'-0" (2 gal/ton)
Shale, sandy, unmeasured

SAMPLING PROCEDURE

The accuracy, and thus the reliability of any analysis, depends on the sample taken, that is, whether it accurately represents the deposit or the point being sampled. It is not particularly easy to obtain a representative sample from any shale section, because of the inherent nature of the material. Primarily, it is important that the sample be taken from beyond the zone of surface weathering, the exception to this being a massive deposit where it has been found that apparently weathering does not effect the shale for more than a few inches in from the surface.

The sampling of certain selected sections undertaken by the author deviated from regular practice, in that the samples represent more of a reconnaissance-type, than does the trench sampling ordinarily utilized. A sampling interval of not less than five feet was established, even though it fell on a particularly lean area. It was hoped that this sampling interval would be sufficient to detect any rich ledge of mineable thickness. However, if an apparently rich seam was discovered, it was sampled and the sample location fixed with relation to the top or bottom of the outcrop. It was observed that generally, the richest portions were more resistant to weathering, and thus were in evidence as ridges protruding from the leaner material.

Aside from this one deviation from regular sampling practice, all of the necessary precautions were taken to insure that the sample would be representative. It must be kept in mind, however, that the sampling was intended to be of a reconnaissance-type, and that a sample represents not an entire formation but rather a point location within the formation. In this manner, an attempt was made to sample a large vertical interval, especially with relation to the Heath formation which has considerable thickness.

Sampling Procedure for the Phosphoria Formation

The "upper phosphatic shale member" of the Phosphoria was sampled in some detail at Daly's Spur (Location 3, Figure 2, page 7) near Dell, Montana, in section 36, T. 8 S., R. 10 W.. The "D" unit (Figure 4, page 12) in this locality is 56 feet thick, and samples were taken at the contacts, and at points eight feet apart across the entire outcrop.

A composite sample, consisting of a portion of shale from each of the above mentioned sample locations, was also taken, as well as a grab sample from the walls of an horizontal coal exploration drift. It was thought that the eight foot sampling interval would detect a mineable thickness of rich shale. However, the possibility of a rich ledge occurring between sample intervals must be considered.

Sampling Procedure for the Heath Formation

The Heath formation, in the vicinity sampled on the north flank of the Big Snowy Mountains, exhibits only scattered outcrops other than where it is capped with the more resistant Amsden formation. Elsewhere it quickly reverts to soil, and thus good exposures do not exist. One location (Location 9, Figure 2, page 7) was available, and that in a fairly deep road cut on section line 25-36, T. 14 N., R. 19 E.. Fifty feet of lower Heath can be observed in this road cut. This outcrop (Figure 5, page 15) was sampled at five foot intervals. The occurrence is characterized by a predominance of thin-bedded oil shale, and petroliferous limestone or limey shale, none of which have considerable thickness. Again, if any noticeably rich strata were present they were sampled. One of these supposedly rich beds was a fossiliferous ledge close to the bottom of the exposure.

The Heath shale was also sampled close to Scott's measured section on Beacon Hill (Location 10, Figure 2, page 7), in section 6, T. 12 N., R 20 E.. There the Heath formation is overlain by approximately 200 feet of resistant Amsden. Again, only a few good outcrops were observed, and those at scattered points, and thus at unknown stratigraphic horizons. Samples were taken at and down hill from the Heath-Amsden contact. A five foot sampling interval was maintained, or at least attempted, with the scarcity of good outcrops controlling the spacing. These samples can be considered to be from the upper-Heath, which in much of the immediate area has been removed by erosion.

Samples Not Collected by the Author

Samples of the middle-Heath were supplied by Mr. James H. Clement of the Shell Oil Company, Billings, Montana. These samples are from the Farmers Union Company Nason No. 1 well (Location 11, Figure 2, page 7), the exact location of which is in section 35, T. 11 N., R. 32 E.. More particularly the samples represented the intervals 5065-5077, 5077-5094, and 5259-5279. In this well the reported tops are Heath--4756, and Otter--5242. The last sample (5259-5279) is probably Otter rather than Heath shale. One other sample of Heath shale was obtained from Mr. Clement, and that from Sure Enough Hill (Location 12, Figure 2, page 7) south of Forest Grove, Montana, in T. 14 N., R. 21 E.. It is not known from which portion of the Heath formation this sample was collected.

The only sample of basal Lodgepole (Paine) to be assayed as an occurrence of black shale and possible oil shale, came from the same source as those above. The sample was collected

35?
see pg. 78

on Crystal Lake Road (Location 20, Figure 2, page 7) in the Big Snowy Mountains, in section 31, T. 12 N., R. 18 W.. The sample was not representative of the entire black shale unit.

CRUSHING, SCREENING, AND SPLITTING OF SAMPLES

The individual samples of oil shale were crushed with a Sturtevant laboratory jaw crusher and rolls. The crushing operation was continued until the shale sample was 100 per cent minus 5-mesh. This precaution was taken to insure a thorough mixing of the rich and lean shale, because the richer material was more resistant to crushing and predominated in the larger sizes.

During the retorting of an oil shale, a certain amount of dust is formed and is carried over into the condenser system with the oil vapors. To overcome this, the minus 5-mesh material was further classified on a 60-mesh screen. The portion saved for the retort charge was all minus 5-mesh plus 60-mesh, and gave a distillate free of sediment and the smaller shale particles.

To insure that a uniform sample was being utilized to make up the retort charge, the minus 5-mesh plus 60-mesh shale was halved on a laboratory sample splitter. The material retained from this operation was thought to be representative of the initial sample.

THE ASSAY RETORT AND CONDENSER SYSTEM

Many field and laboratory methods have been proposed for determining the oil yield from samples of oil shale. The United States Bureau of Mines has for some time been studying the assaying of oil shales, and has developed an efficient method and apparatus. Figure 6, page 30, illustrates the oil shale assay retort and condenser system fabricated and operated by the author. This apparatus is basically similar to that used by the Bureau of Mines (10, p 143), the major difference being in the retort itself, and in the method of maintaining a sound contact between its lid and base.

Government specifications recommend that a pint-size Mercury retort be used, and that a lid-to-base seal be maintained by grinding the two parts together using No. 220 carborundum and water. As no such retort was available, the author had one machined from stock steel. The volume was altered in such manner that approximately 50-70 grams of material would make up a full retort charge. A special lid-to-base contact was machined on the two parts, such that a lip on the base seats in a groove in the lid. This contact was maintained in the same manner as specified by the Bureau of Mines, with the exception that a copper gasget was inserted between the base and lid, before the latter was secured. This procedure insured a gas-tight seal, which could be maintained with a minimum of hand grinding between assays. The Bureau of Mines suggests also (10, 143), that a mixture of pulverized

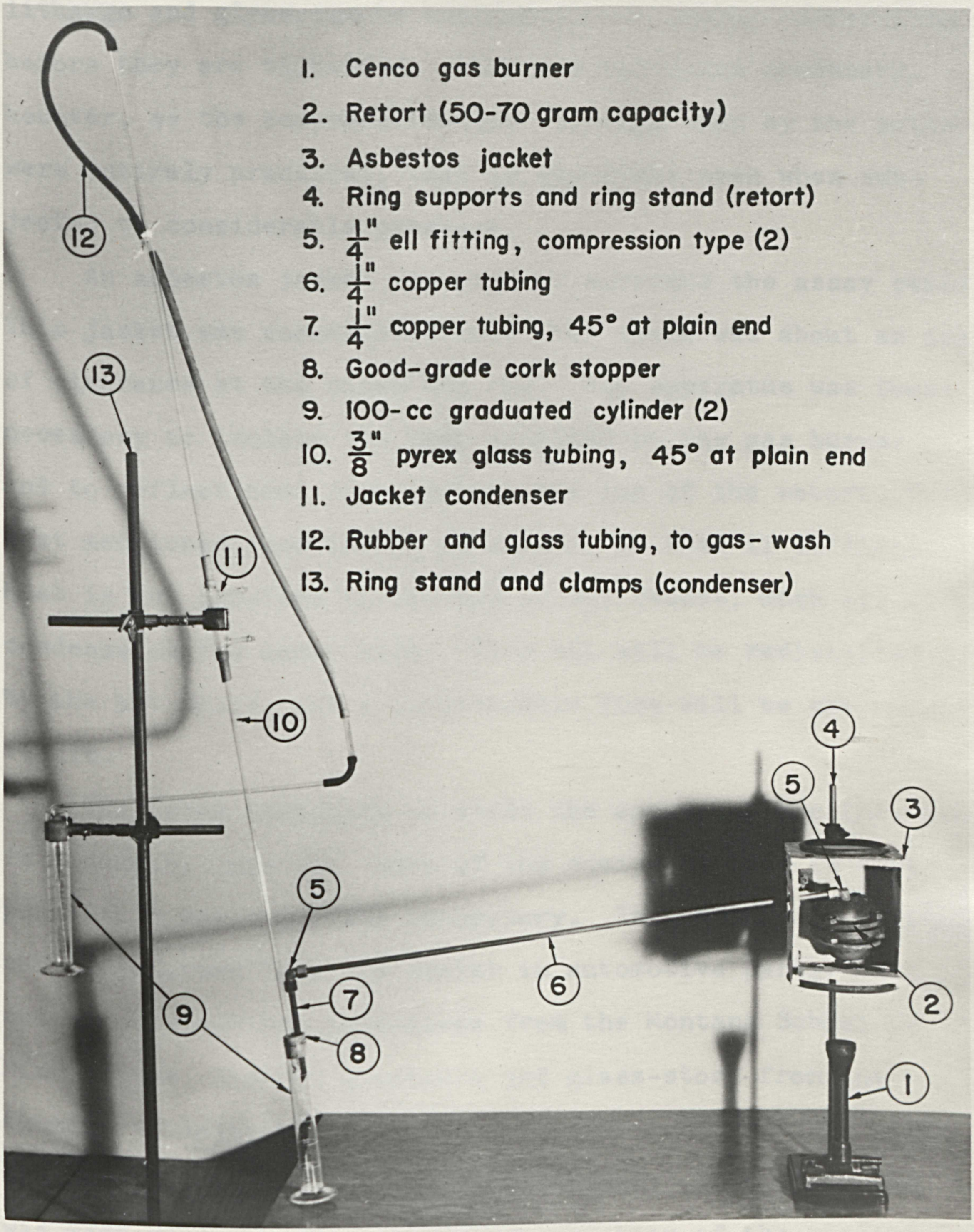


FIGURE 6--Oil Shale Assay Retort and Condenser System

litharge and glycerine be applied to the tubing connections before they are tightened. This was not found necessary, however, as the compression-type fittings used by the author were entirely practical, that is gas-tight even when subjected to considerable pressure.

An asbestos jacket was used to surround the assay retort. This jacket was constructed such that there was about an inch of clearance at the sides and top. The apparatus was found necessary to isolate the heat supplied by the gas burner, and to reflect heat down against the top of the retort. This last mentioned function is necessary, in that if sufficient heat is not supplied to the top of the retort, much oil will condense on its under side. This oil will be redistilled by the hot shale, and a considerable loss will be the end result.

The parts necessary to erect the apparatus are indicated in Figure 6, page 30. Much of the equipment used is that present in any chemistry laboratory. The tubing and fittings can be obtained from any dealer in automotive parts. The author obtained the pipe-stock from the Montana School of Mines shops, and the glassware and glass-stock from the Chemistry Department. The glass jacket condenser was made specifically to fit the reflux condenser. This apparatus was made small to give maximum circulation of the cooling water.

ASSAYING OIL SHALES FOR OIL YIELD

The accurate determination of the oil yield from any oil shale sample is not a simple process, as it has to do with "manufacturing" the oil in the retort, and also the removal, condensation, and recovery of the oil. The actual retorting is a very simple and yet important part of the oil shale assay, as the yield and character of the oil produced depend largely on it. However, emphasis must also be placed on the maintenance of the retort, and the measurement of the recovered oil, both of which must be faithfully undertaken before any assay can be proclaimed accurate and entirely successful.

No attempt was made to retain and analyze the gases evolved during any distillation. The evolution of these gases begins at a temperature below that of the first crude oil produced, and continues during the oil-producing period. This early-formed evolution of gas, which was found to be quite rich in hydrogen sulphide, drops off as the distillation progresses and the temperature increases, and is replaced to a large extent by the aromatics and the lower members of the hydrocarbon series. In a large operation, these gases would be of value for their heat content and combustibility.

Ammonium sulphate is another product recoverable from oil shales. No attempt was made to analyze the shales for their nitrogen content, from which this ammonium sulphate would be produced.

Maintenance of the Retort

Extreme care was exercised in the preparation and maintenance of the contact surfaces on the lid and base of retort. It was early found, that even though these surfaces were maintained properly, a gas-tight contact could not be obtained unless they were kept perfectly clean and aligned while securing the lid. The copper gasget, having greater expansibility than steel when heated, further insured against the failure of this all-important lid-to-base seal. Before any assay, this very important contact was tested by immersing the retort in water, and applying back-pressure through the delivery tube (7). If the seal was not perfect, that is if small air bubbles appeared, the lid was reseated and again secured. A second attempt was generally sufficient, and a proper contact thus maintained. After a little experience was gained, the retort could be made ready for an assay in approximately five minutes.

Operation of the Assay Retort

Just enough of the minus 5-mesh plus 60-mesh shale was weighed out to fill the retort. This charge generally consisted of from 50 to 80 grams of the material. The lid of the retort was then secured, and the retort tested for leakage as described above. The retort-delivery tube arrangement (refer to Figure 6, page 30) was then placed in the ring support, the asbestos jacket adjusted, and the receiving graduate and reflux condenser fixed tightly in place, paying particular attention to the contact between the cork stopper, delivery tube, and receiving graduate for gas-tightedness.

A very small flame was used at first, such that no oil would appear within one hour after starting the assay run. It was generally the case, however, that considerable water appeared in the graduate before the hour was up. "One hour is about the minimum time in which the shale charge can be brought up to the initial distillation temperature and yet possess a fairly even temperature throughout. Some shales begin to yield vapors at approximately 250° C., whereas others show no signs of oil vapors until 375° C. is reached. Before the distillation makes much progress, the interior of the coolest shale particle should be at least as hot as the vaporizing temperature of the oil involved, otherwise vapors will migrate to the central or coolest part and condense there, causing losses of oil by cracking and redistillation of the condensed oil." (10, p 144).

After approximately 1 cc of crude oil had accumulated, the temperature was increased. If the initial flame was such that the first crude oil appeared in about one hour, it was then considered safe to double the size of the flame, and thereafter to increase the heat every 20 minutes by an equal increment. "It should be remembered that the quantity of oil recovered will vary for the same shale sample if the rate of retorting varies, the greater quantity being obtained with rapid retorting, and, conversely, a much less amount with a long distillation period. The distillation should be rapid however, when the maximum yield of oil is desired, in order to prevent stagnation of oil vapors within the hot retort or connection, and in all cases should progress at a uniform rate." (10, p 145). If, at any time during the distillation of a sample, droplets of distillate were observed collecting near the top of the reflux condenser, the rate of heating was retarded slightly.

Assuming that the distillation had progressed uniformly, a point was eventually reached where the rate of accumulation of the crude shale oil decreased very suddenly. When this became apparent, the heat was increased once more. This last increase in temperature was sufficient to finish the assay run. The last crude to be distilled off was generally followed by white noninflammable vapors of shale gas, which were a further indication that the distillation was complete. At this point, the bottom of the retort was characteristically a very dull red, which temperature is well above the final oil-yielding temperature of the oil shale. In any case, the heating was continued for approximately fifteen minutes to insure complete drainage of the delivery tube and reflux condenser.

Throughout any distillation, the gases evolved were led from the top of the reflux condenser to a water-wash in a second graduated cylinder, the water therein ultimately becoming quite strongly acid. A portion of this water was utilized in back-washing the reflux condenser, the water and that distillate thus removed being collected in the same receiving graduate as the crude shale oil.

Measurement of Volume of Distillate

To determine accurately the amount of crude oil recovered, a gravimetric method was used in favor of a simple and rapid volumetric one. The receiving graduate, with included distillate and wash-water, was weighed while warm, and was set aside for a certain period of time to allow that material held in suspension to settle. This weight was expressed in grams for the sake of convenience in calculating the yield. When sufficient time has been allowed for settling, all but one or two cubic centimeters of the recovered crude was removed with a pipette, and the oil saved for a specific gravity determination. It was assumed that this sample was representative of the total amount recovered, no matter what the volume. Care was taken in this removal operation, such that no water and sediment were withdrawn with the crude oil. That oil remaining in the receiving graduate was diluted with 10 to 15 cubic centimeters of petroleum ether, and the walls of the cylinder washed down in the same operation. The cylinder was then agitated to thoroughly mix the crude oil and solvent. This mixture was again set aside for a time until all of the water and sediment had settled from the oil. The oil-petroleum ether emulsion was then removed with a pipette, nearly to the level of the water, and was discarded. This washing process was repeated until the petroleum ether that was being added remained clear, that is until no crude oil remained in the receiving cylinder. The clear petroleum ether was then removed to approximately the level of the water, and the remainder by evaporation. The receiving cylinder, which contained only sediment and water, was then weighed and the value obtained subtracted from the first determined weight. This difference was the total weight of oil obtained from the shale.

As the amount of oil recovered from most of the oil shales was on the order of one or two cubic centimeters, the measurement of its specific gravity presented a problem. Three pipette-like specific gravity flasks were fabricated from standard glass tubing. Each had a different volume, the reservoirs accomodating 0.35, 0.52, and 3.00 cubic centimeters respectively. The ends of these flasks were terminated with capillary restrictions. In each case, the rear restriction had etched on it a fine hair-like mark to which level the flask was filled. Each of these flasks was calibrated by first weighing it empty, and then when filled with water at room temperature. These measurements gave the volume of each flask, as one gram of water at room temperature (60° F.) occupies a volume of one cubic centimeter. To measure the specific gravity of the crude shale oil first removed, the appropriate flask is filled and its weight determined. The choice of flasks was governed by the amount of crude shale oil available from any distillation. The figure obtained by subtracting the weight of the empty flask from the above weight, was the weight of a known volume of the crude shale oil.

Knowing the specific gravity of the oil obtained in any assay, the volume of the crude shale oil recovered was determined by dividing the total weight of oil recovered in any assay by the specific gravity of the oil. The result thus obtained was the true volume of oil in cubic centimeters, at the temperature of the specific gravity determination.

Calculation of Yield

The volume of oil recovered in cubic centimeters was converted into gallons of oil per ton of oil shale by the formula:

$$\text{gallons per ton} = \frac{\text{volume of oil in cm}^3 \times 240}{\text{weight of shale sample}}$$

The conversion factor is obtained by clearing the units used in converting cubic centimeters per gram into gallons per ton.

Each shale sample, representing one sample location, was assayed two or more times, the gravimetric determination of volumes generally agreeing within one per cent. This reproducible accuracy is equal to that maintained by the United States Bureau of Mines using the same method of determining the volume, but a slightly different oil shale assay retort. The yields from two or more assays were averaged, the result representing the oil recoverable from the initial sample.

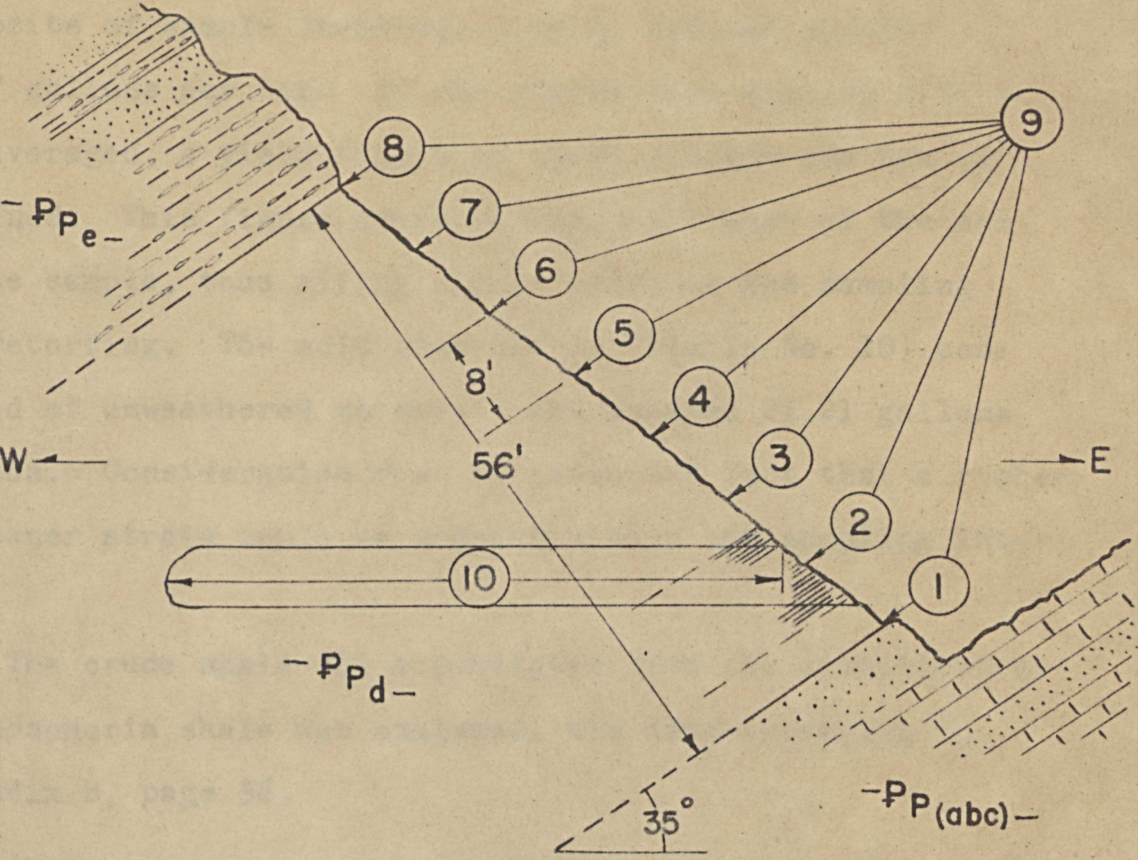
EXPERIMENTAL DATA

The author's data is concerned with shale samples from the Phosphoria, Heath, and basal Lodgepole formations. These oil shale samples represented locations on which no previous work had been done. The information compiled appears in the appendix.

It is evident from this data, that the most valuable occurrence of oil shale in Montana is in the Phosphoria formation, and further, that it is restricted to unit "D" within the formation. One sample of lower-Heath was likewise good, the information appearing in Appendix E, page 76. However, this petroliferous black shale should be further sampled and evaluated. One sample of black shale from the immediate base of the Lodgepole was assayed, and was found to be slightly petroliferous. Again, the nature of this one sample is not to be taken as indicative of the entire black shale unit.

Yields From the Phosphoria Formation

The "D" unit of the Phosphoria formation was systematically sampled at the location shown in Figures 3 and 4, page 12. Figure 7, page 40, is a generalized vertical section of this occurrence, with the sample locations and yield from each depicted thereon. This data shows that there are two fairly rich horizons present (Samples 6 and 7), and these at points 8 and 16 feet below the upper contact--both samples assayed close to 20 gallons per ton. Sample No. 9 was a



(1) -8.56 gallons per ton of shale
(2) -13.69
(3) -15.00
(4) -16.10
(5) -8.10
(6) -19.55
(7) -19.69
(8) -10.20

13.86 average

(9) -14.07 Composite sample
(10) -21.21 Adit grab sample

FIGURE 7-- Generalized Vertical Section of Phosphoria Unit "D", Section 36, T. 8 S., R. 10 W., Showing Sample Locations and yields.

composite of sample locations 1 to 8, and had a value of 14.07 gallons per ton. If the yields from samples 1 to 8 are averaged, a yield figure of 18.86 gallons per ton is obtained. This figure compares well with that of the composite sample, thus giving a good check on the sampling and retorting. The adit grab sample (Sample No. 10) consisted of unweathered material, and assayed 21.21 gallons per ton. Consideration must be given the fact that a richer or leaner strata could be present within the sampling interval.

The crude shale oil accumulated from the distillations of Phosphoria shale was analyzed, the data appearing in Appendix B, page 58.

Yields From the Heath Formation

Samples from the lower, middle, and upper portions of the Heath formation were assayed, the best yield coming from the most basal portion. The samples of upper-Heath yielded from a trace to 1.5 gallons per ton. The middle-Heath shale, from the intervals 5065-5077, 5077-5094, and 5259-5279 (Otter) in the Farmers Union Company Nason No. 1 well, gave only 1 to 1.5 gallons per ton. Samples from lower-Heath, in sections 25 and 36, T. 14 N., R. 19 E., assayed 1 to 6 gallons per ton. Supposedly rich samples from the same location gave 3 and 5 gallons per ton respectively. The lower-most portion of the Heath formation was found to have the best yield of any shale tested. A single sample of this petroliferous black shale assayed at 26 gallons of oil per ton of shale.

One shale sample from Sure Enough Hill just south of Forest Grove, Montana, gave 10 gallons per ton. The exact stratigraphic position of this sample is unknown.

From the above tabulation it is apparent that with the exception of the most basal portion, which should be further evaluated, the Heath formation is only slightly petroliferous. It must be remembered also, that much of the formation is thin-bedded, and that probably mineable thicknesses of rich shale do not exist.

Yield From the Basal Lodgepole

Only one sample of this material was available for assaying, and that from Crystal Lake Road in the Big Snowy Mountains. In this locality, 20 feet of black shale occurs at the base of the Lodgepole formation. The sample, which is not representative of the entire black shale unit, assayed at approximately 1.5 gallons of oil per ton.

SUMMARY AND CONCLUSIONS

Montana's most important oil shale occurrences are summarized below. The author's experimental data substantiates the information already available, and supplements it to the extent of recommending that one occurrence be further evaluated. Much of the information below is a result of the work of Condit (4), Gavin (10), and Reeves (16).

Tertiary Oil Shale

Samples from some beds with a thickness of five feet will yield as much as 24 gallons of oil per ton, and will contain from 0.1 to 0.9 per cent nitrogen. The highest yield was obtained from an impure earthy lignite bed ten inches thick, cropping out on Keystone Creek in section 17, T. 13 S., R. 10 W., in Beaverhead County, Montana, (4, p 34). This lignitic bed assayed at 36 gallons of oil per ton.

Phosphoria Oil Shale

In the Dell-Dillon area, where the Phosphoria oil shale is at its best, the richest beds three feet thick will yield 30 gallons of oil to the ton. These units are not of mineable thickness, but have a relatively high phosphate content. Seams of workable thickness will yield up to 20 gallons of oil per ton, and will contain the equivalent of 71 pounds of ammonium sulphate per ton, and about two per cent phosphorous, calculated as phosphorous pentoxide. (10, p 24). The author's data, although only concerned with the oil yield of the shale as it occurs at Daly's Spur, Montana, further substantiates Gavin's findings.

The Heath Formation

In 1931, Reeves (16) made the observation that low grade oil shales occur in the middle part of the Heath formation. He further indicated that none of the beds were of prospective commercial value. It was stated also, that beds a few inches thick that would yield 20 to 30 gallons of oil per ton might be present, but that no strata a foot or more in thickness that would yield over 10 gallons of oil per ton are in existence. (16, p 148). The assaying undertaken by the author tends to substantiate the above information. One possible exception is the extreme basal Heath, which was found by the author to be quite petroliferous. However, the thickness and areal extent of this unit are not known.

Conclusions

In summarizing the data available on Montana's oil shales, it is evident that only the Phosphoria formation has proven importance. The Heath shale is only slightly petroliferous in its middle and upper portions. A few rich beds of less than one foot in thickness may be present, but this is not a mineable thickness. The extreme basal portion has yet to be sampled and assayed in any detail. The ultimate evaluation of this unit may prove the exception. The Colorado shale, and the black shale at the base of the Lodgepole (Paine) are only slightly petroliferous at best. Some of the Tertiary shales or lignites have a relatively high yield, but this fact is offset by their small thickness and limited areal extent.

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APPENDICES

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 1

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	54.85	57.44	55.38
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	78.96	81.81	78.85
Weight of Receiving Graduate with Crude Shale Oil Removed	77.05	79.83	76.90
Weight of Crude Shale Oil Recovered	1.91	1.98	1.95
DETERMINATION OF SPECIFIC GRAVITY			
Weight of cc of Crude Shale Oil	- - -	- - - -	- - - -
$S.G. = \frac{\text{Weight of cc Crude}}{\text{Volume of S.G. Flask}}$	assume 0.977	assume 0.977	assume 0.977
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.95	2.03	1.99
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	8.57	8.50	8.65
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	8.56 gallons/ton		

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 2

LOCATION: Daly's Spur, section 36, T. 8 S., R 10 W.

Assay Number	1	2	3
Weight of Shale Sample	57.54	56.62	63.43
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	71.60	76.31	71.09
Weight of Receiving Graduate with Crude Shale Oil Removed	68.32	73.11	67.36
Weight of Crude Shale Oil Recovered	3.28	3.20	3.63
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.52 cc of Crude Shale Oil	0.52	0.52	0.52
$S.G. = \frac{\text{Weight of 0.52 cc of Crude}}{\text{Volume of S.G. Flask (0.52 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	3.28	3.20	3.63
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	13.69	13.58	13.75
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	13.69 gallons/ton		

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 3

LOCATION: Daly's Spur, Section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	59.91	62.79	63.29
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	76.29	76.46	82.03
Weight of Receiving Graduate with Crude Shale Oil Removed	72.59	72.57	78.00
Weight of Crude Shale Oil Recovered	3.70	3.89	4.03
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.52 cc of Crude Shale Oil	0.52	0.52	0.52
$S.G. = \frac{\text{Weight of } 0.52 \text{cc Crude}}{\text{Volume of S.G. Flask (0.52 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	3.70	3.89	4.02
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	14.80	14.89	15.29
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	15.0 gallons/ton		

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 4

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	56.76	59.70	59.34
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	71.73	73.97	73.87
Weight of Receiving Graduate with Crude Shale Oil Removed	68.07	69.97	69.98
Weight of Crude Shale Oil Recovered	3.66	4.00	3.89
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.52 cc of Crude Shale Oil	0.51	0.51	0.51
$S.G. = \frac{\text{Weight of 0.52cc Crude}}{\text{Volume of S.G. Flask (0.52 cc)}}$	0.98	0.98	0.98
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	3.74	4.08	3.98
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	15.79	16.39	16.10
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	16.10 gallons/ton		

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 5

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	64.93	63.38	64.79
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	74.90	78.07	76.54
Weight of Receiving Graduate with Crude Shale Oil Removed	72.73	76.01	74.34
Weight of Crude Shale Oil Recovered	2.17	2.96	2.20
DETERMINATION OF SPECIFIC GRAVITY			
Weight of ___cc of Crude Shale Oil	---------	--------	---------
$S.G. = \frac{\text{Weight of \_\_\_\_cc of Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	assume 1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	2.17	2.96	2.20
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	8.02	7.82	8.15
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	8.00 gallons/ton		

APPENDIX A

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 6

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	56.29	55.97	57.65
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	85.61	76.88	75.80
Weight of Receiving Graduate with Crude Shale Oil Removed	81.01	72.29	71.09
Weight of Crude Shale Oil Recovered	4.60	4.59	4.71
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.52 cc of Crude Shale Oil	0.52	0.52	0.52
$S.G. = \frac{\text{Weight of 0.52 cc Crude}}{\text{Volume of S.G. Flask (0.52 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	4.60	4.59	4.71
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	19.60	19.69	19.35
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	19.55 gallons/ton		

APPENDIX A

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 7

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	50.96	55.43	53.73
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	78.21	77.96	78.74
Weight of Receiving Graduate with Crude Shale Oil Removed	74.06	73.37	74.36
Weight of Crude Shale Oil Recovered	4.15	4.59	4.38
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 3.00 cc of Crude Shale Oil	3.00	3.00	3.00
$S.G. = \frac{\text{Weight of 3.00 cc Crude}}{\text{Volume of S.G. Flask (3.00 CC)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	4.15	4.59	4.38
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	19.55	19.92	19.59
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	19.69 gallons/ton		

APPENDIX A

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 8

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	56.94	62.10	58.37
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	72.71	79.05	76.43
Weight of Receiving Graduate with Crude Shale Oil Removed	70.36	76.27	74.00
Weight of Crude Shale Oil Recovered	2.35	2.78	2.43
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.52cc of Crude Shale Oil	0.52	0.52	0.52
S.G. = $\frac{\text{Weight of 0.52 cc Crude}}{\text{Volume of S.G. Flask (0.52 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
Volume = $\frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	2.35	2.78	2.43
DETERMINATION OF YIELD IN GAL/TON			
Yield (gal/ton) = $\frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	9.89	10.73	9.98
DETERMINATION OF AVERAGE YIELD			
Average Yield = $\frac{\text{Sum of Assays}}{\text{Number of Assays}}$	10.20 gallons/ton		

APPENDIX A

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 9 (Composite)

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	63.18	58.96	62.43
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	77.49	75.89	77.78
Weight of Receiving Graduate with Crude Shale Oil Removed	73.76	72.47	74.12
Weight of Crude Shale Oil Recovered	3.73	3.42	3.66
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.52cc of Crude Shale Oil	0.52	0.52	0.52
$S.G. = \frac{\text{Weight of } 0.52 \text{ cc of Crude}}{\text{Volume of S.G. Flask (0.52 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	3.73	3.42	3.66
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	14.15	13.94	14.07
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	14.07 gallons/ton		

OIL SHALE ASSAY RECORD

SHALE: Phosphoria, Unit "D", Sample No. 10 (Adit)

LOCATION: Daly's Spur, section 36, T. 8 S., R. 10 W.

Assay Number	1	2	3
Weight of Shale Sample	60.55	59.73	58.93
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	81.29	79.98	78.74
Weight of Receiving Graduate with Crude Shale Oil Removed	75.86	74.71	73.60
Weight of Crude Shale Oil Recovered	5.43	5.27	5.14
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 3.00 cc of Crude Shale Oil	3.00	3.00	3.00
S.G. = $\frac{\text{Weight of 3.00 cc Crude}}{\text{Volume of S.G. Flask (3.00 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
Volume = $\frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	5.43	5.27	5.14
DETERMINATION OF YIELD IN GAL/TON			
Yield (gal/ton) = $\frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	21.5	21.21	5.14
DETERMINATION OF AVERAGE YIELD			
Average Yield = $\frac{\text{Sum of Assays}}{\text{Number of Assays}}$	21.21 gallons/ton		

APPENDIX A

Distillation Analysis of Shale Oil

Shale from Daly's Spur, Montana
Specific Gravity of Oil-- 1.00
Initial Sample Volume-- 46 cc
Percentage of Tops-- 52.22
Percentage of Water-- trace
Specific Gravity of Residuum-- 0.99
Regulation: ASTM Designation D216-40 (Distillation of Natural Gasoline)
Remarks: Oil is composite of all Phosphoria assays.

Record of Distillation

(First drop over 54° C.)

Temperature, ° C.	Per cent cut	Sum per cent
Up to 76	2.18	---
76 -- 96	10.88	13.06
96 -- 206	10.88	23.94
206 -- 264	10.88	34.82
264 -- 267	10.88	45.70
264 -- 278	6.52	52.22

(1) The sum of all fractions distilling at atmospheric pressure below 200° C. is reported as gasoline and naphtha.
(2) 200° C. to 275° C. -- kerosene.
(3) 275° C. and up -- gas oil and heavier oils. All distillate collected below 278° C. is reported as tops.

$$\frac{8.0}{46.0} \times 100.0 = 17.4\% \text{ gasoline and naphtha}$$

$$\frac{15.2}{46.0} \times 100.0 = 33.0\% \text{ kerosene}$$

$$\frac{22.8}{46.0} \times 100.0 = 49.6\% \text{ gas oil and heavier oils}$$

APPENDIX B

OIL SHALE ASSAY RECORD

SHALE: Upper Heath shale

LOCATION: Beacon Hill, section 6, T. 12 N., R. 20 E.

Assay Number	1	2	3
Weight of Shale Sample	79.43	78.76	--------
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	--------	--------	--------
Weight of Receiving Graduate with Crude Shale Oil Removed	--------	--------	--------
Weight of Crude Shale Oil Recovered	--------	--------	--------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of----cc of Crude Shale Oil	--------	--------	--------
$S.G. = \frac{\text{Weight of----cc Crude}}{\text{Volume of S.G. Flask}}$	--------	--------	--------
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	--------	--------	--------
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	trace	trace	--------
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	trace		

APPENDIX C

OIL SHALE ASSAY RECORD

SHALE: Upper Heath shale

LOCATION: Beacon Hill, section 6, T. 12 N., R. 20 E.

Assay Number	1	2	3
Weight of Shale Sample	70.52	71.43	69.79
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	--------	--------	--------
Weight of Receiving Graduate with Crude Shale Oil Removed	--------	--------	--------
Weight of Crude Shale Oil Recovered	--------	--------	--------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of ____cc of Crude Shale Oil	--------	--------	--------
$S.G. = \frac{\text{Weight of ____cc Crude}}{\text{Volume of S.G. Flask}}$	--------	--------	--------
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	--------	--------	--------
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	trace	trace	trace
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	trace		

OIL SHALE ASSAY RECORD

SHALE: Upper Heath shale

LOCATION: Beacon Hill, section 6, T. 12 N., R. 20 E.

Assay Number	1	2	3
Weight of Shale Sample	70.95	71.43	69.47
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	72.18	77.67	75.43
Weight of Receiving Graduate with Crude Shale Oil Removed	71.74	77.20	75.02
Weight of Crude Shale Oil Recovered	0.44	0.47	0.41
DETERMINATION OF SPECIFIC GRAVITY			
Weight of --- cc of Crude Shale Oil	-----	------	-------
$S.G. = \frac{\text{Weight of cc Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	assume 1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	0.44	0.47	0.41
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	1.47	1.58	1.42
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	1.49 gallons/ton		

APPENDIX C

OIL SHALE ASSAY RECORD

SHALE: Upper Heath shale

LOCATION: Beacon Hill, section 6, T. 12 N., R. 20 E.

Assay Number	1	2	3
Weight of Shale Sample	72.79	70.13	-------
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	--------	--------	-------
Weight of Receiving Graduate with Crude Shale Oil Removed	--------	--------	-------
Weight of Crude Shale Oil Recovered	--------	--------	-------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of----cc of Crude Shale Oil	--------	--------	-------
$S.G. = \frac{\text{Weight of----cc Crude}}{\text{Volume of S.G. Flask}}$	--------	--------	-------
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	--------	--------	--------
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	trace	trace	-------
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	trace		

APPENDIX C

OIL SHALE ASSAY RECORD

SHALE: Middle Heath, section 35, T. 11 N., R. 32 E.

LOCATION: Farmers Union Co. Nason No. 1 well, 5065-5077

Assay Number	1	2	3
Weight of Shale Sample	74.12	63.72	-------
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	70.98	69.43	-------
Weight of Receiving Graduate with Crude Shale Oil Removed	70.52	69.05	-------
Weight of Crude Shale Oil Recovered	0.46	0.38	-------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of --- cc of Crude Shale Oil	-------	-------	-------
S. G. = $\frac{\text{Weight of --- cc Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	-------
DETERMINATION OF VOLUME RECOVERED			
Volume = $\frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	0.46	0.38	-------
DETERMINATION OF YIELD IN GAL/TON			
Yield (gal/ton) = $\frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	1.49	1.43	-------
DETERMINATION OF AVERAGE YIELD			
Average Yield = $\frac{\text{Sum of Assays}}{\text{Number of Assays}}$	1.46 gallons/ton		

APPENDIX D

OIL SHALE ASSAY RECORD

SHALE: Middle Heath, section 35, T. 11 N., R. 32 E.

LOCATION: Farmers Union Co. Nason No. 1 well, 5077-5094

Assay Number	1	2	3
Weight of Shale Sample	97.24	88.78	--------
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	74.95	73.77	--------
Weight of Receiving Graduate with Crude Shale Oil Removed	74.60	73.46	--------
Weight of Crude Shale Oil Recovered	0.35	0.31	--------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of---- cc of Crude Shale Oil	-------	--------	--------
$S.G. = \frac{\text{Weight of -- cc Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	------
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	0.35	0.31	-------
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	0.86	0.84	------
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	0.85 gallons/ton		

APPENDIX D

OIL SHALE ASSAY RECORD

SHALE: Middle Heath, section 35, T. 11 N., R. 32 E.

LOCATION: Farmers Union Co. Nason No. 1 well, 5259-5279 (Otter?)

Assay Number	1	2	3
Weight of Shale Sample	68.61	67.74	-------
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	71.10	72.43	-------
Weight of Receiving Graduate with Crude Shale Oil Removed	70.70	72.05	-------
Weight of Crude Shale Oil Recovered	0.40	0.37	-------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of ---cc of Crude Shale Oil	-------	-------	-------
$S.G. = \frac{\text{Weight of --- cc of Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	-------
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	0.40	0.38	-------
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	1.40	1.37	-------
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	1.385 gallons/ton		

APPENDIX D

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: Top of 1st road cut

Assay Number	1	2	3
Weight of Shale Sample	86.51	85.19	76.70
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	67.77	68.93	64.75
Weight of Receiving Graduate with Crude Shale Oil Removed	66.35	67.62	63.53
Weight of Crude Shale Oil Recovered	1.42	1.31	1.22
DETERMINATION OF SPECIFIC GRAVITY			
Weight of----cc of Crude Shale Oil	--------	---------	---------
$S.G. = \frac{\text{Weight of----cc Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	assume 1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.42	1.311	1.22
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	3.94	3.70	3.82
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	3.82 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: 5' down 1st road cut

Assay Number	1	2	3
Weight of Shale Sample	78.29	73.67	77.43
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	65.68	66.94	63.91
Weight of Receiving Graduate with Crude Shale Oil Removed	65.27	66.59	63.50
Weight of Crude Shale Oil Recovered	0.41	0.35	0.41
DETERMINATION OF SPECIFIC GRAVITY			
Weight of --- cc of Crude Shale Oil	------	-------	-------
$S.G. = \frac{\text{Weight of --- cc Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	assume 1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	0.41	0.35	0.41
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	1.26	1.14	1.27
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	1.22 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, section 25 and 36, T. 14 N., R. 19 E.

LOCATION: 10' down 1st road cut

Assay Number	1	2	3
Weight of Shale Sample	70.34	75.98	71.43
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	70.93	72.93	68.75
Weight of Receiving Graduate with Crude Shale Oil Removed	70.33	72.22	68.15
Weight of Crude Shale Oil Recovered	0.60	0.71	0.60
DETERMINATION OF SPECIFIC GRAVITY			
Weight of----cc of Crude Shale Oil	--------	--------	--------
$S.G. = \frac{\text{Weight of --- cc of Crude}}{\text{Volume of S.G. Flask}}$	assume 1.0	assume 1.0	assume 1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	0.60	0.71	0.60
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	2.05	2.24	2.02
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	2.10 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, section 25 and 36, T. 14 N., R. 19 E.

LOCATION: 15' down 1st road cut

Assay Number	1	2	3
Weight of Shale Sample	73.63	71.43	74.07
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	69.49	72.97	68.53
Weight of Receiving Graduate with Crude Shale Oil Removed	68.44	72.02	67.43
Weight of Crude Shale Oil Recovered	1.05	0.95	1.10
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35 cc of Crude Shale Oil	0.35	0.35	0.35
$\text{S.G.} = \dfrac{\text{Weight of 0.35 cc Crude}}{\text{Volume of S.G. Flask}}$ (0.35 cc)	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \dfrac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.05	0.95	1.10
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \dfrac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	3.42	3.20	3.56
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \dfrac{\text{Sum of Assays}}{\text{Number of Assays}}$	3.39 gallons/ton		

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APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: Top of 2nd road cut

Assay Number	1	2	3
Weight of Shale Sample	68.33	70.77	67.43
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	72.58	73.73	71.30
Weight of Receiving Graduate with Crude Shale Oil Removed	70.92	72.01	69.70
Weight of Crude Shale Oil Recovered	1.66	1.72	1.60
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35 cc of Crude Shale Oil	0.35	0.35	0.35
$S.G. = \frac{\text{Weight of 0.35 cc Crude}}{\text{Volume of S.G. Flask (0.35 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.66	1.72	1.60
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	5.83	5.84	5.69
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	5.78 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: 5' down 2nd road cut

Assay Number	1	2	3
Weight of Shale Sample	69.87	70.43	72.73
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	72.83	71.94	73.74
Weight of Receiving Graduate with Crude Shale Oil Removed	71.12	70.07	71.92
Weight of Crude Shale Oil Recovered	1.71	1.87	1.82
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35cc of Crude Shale Oil	0.35	0.35	0.35
$S.G. = \frac{\text{Weight of 0.35cc Crude}}{\text{Volume of S.G. Flask (0.35 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.71	1.87	1.82
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	5.88	6.35	6.0
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	6.07 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: 10' down 2nd road cut

Assay Number	1	2	3
Weight of Shale Sample	73.60	72.43	74.10
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	77.42	73.77	74.93
Weight of Receiving Graduate with Crude Shale Oil Removed	75.69	72.15	73.12
Weight of Crude Shale Oil Recovered	1.73	1.62	1.81
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35cc of Crude Shale Oil	0.35	0.35	0.35
$S.G. = \frac{\text{Weight of } 0.35\text{cc Crude}}{\text{Volume of S.G. Flask}}$ (0.35 CC)	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.73	1.62	1.81
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	5.64	5.37	5.86
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	5.62 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: 1st road cut, fossiliferous limey shale

Assay Number	1	2	3
Weight of Shale Sample	80.22	72.79	73.43
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	70.54	69.43	73.42
Weight of Receiving Graduate with Crude Shale Oil Removed	69.58	68.60	72.50
Weight of Crude Shale Oil Recovered	0.96	0.83	0.92
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35 cc of Crude Shale Oil	0.33	0.34	0.33
$S.G. = \frac{\text{Weight of } 0.35 \text{ cc Crude}}{\text{Volume of S.G. Flask } (0.35\text{ cc})}$	0.94	0.97	0.94
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.02	0.86	0.98
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	3.06	2.82	3.20
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	3.03 gallons/ton		

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: 2nd road cut, fossiliferous limey shale

Assay Number	1	2	3
Weight of Shale Sample	80.13	79.43	79.93
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	66.14	67.82	72.47
Weight of Receiving Graduate with Crude Shale Oil Removed	64.63	66.37	71.01
Weight of Crude Shale Oil Recovered	1.51	1.45	1.46
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35 cc of Crude Shale Oil	0.34	0.34	0.34
$S.G. = \frac{\text{Weight of 0.35 cc Crude}}{\text{Volume of S.G. Flask (0.35 cc)}}$	0.97	0.97	0.97
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.55	1.50	1.52
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	4.65	4.50	4.55
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	4.57 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: 2nd road cut, fossiliferous limey shale

Assay Number	1	2	3
Weight of Shale Sample	82.51	83.45	82.74
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	73.79	74.68	75.47
Weight of Receiving Graduate with Crude Shale Oil Removed	72.73	73.53	74.30
Weight of Crude Shale Oil Recovered	1.06	1.15	1.17
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35cc of Crude Shale Oil	0.35	0.35	0.35
$S.G. = \frac{\text{Weight of 0.35cc Crude}}{\text{Volume of S.G. Flask (0.35 cc)}}$	1.0	1.0	1.0
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	1.06	1.15	1.17
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	3.08	3.31	3.40
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	3.26 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Lower Heath, sections 25 and 36, T. 14 N., R. 19 E.

LOCATION: Black fissile shale, conodont-bearing ?

Assay Number	1	2	3
Weight of Shale Sample	59.88	60.05	60.24
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	82.66	79.37	74.74
Weight of Receiving Graduate with Crude Shale Oil Removed	76.69	73.31	68.63
Weight of Crude Shale Oil Recovered	5.97	6.06	6.11
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35 cc of Crude Shale Oil	0.32	0.32	0.32
$S.G. = \frac{\text{Weight of 0.35 cc Crude}}{\text{Volume of S.G. Flask (0.35 cc)}}$	0.915	0.915	0.915
DETERMINATION OF VOLUME RECOVERED			
$\text{Volume} = \frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	6.525	6.63	6.67
DETERMINATION OF YIELD IN GAL/TON			
$\text{Yield (gal/ton)} = \frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	26.2	26.5	26.6
DETERMINATION OF AVERAGE YIELD			
$\text{Average Yield} = \frac{\text{Sum of Assays}}{\text{Number of Assays}}$	26.4 gallons/ton		

APPENDIX E

OIL SHALE ASSAY RECORD

SHALE: Heath formation, black shale

LOCATION: Sure Enough Hill, section (?), T. 14 N., R. 21 E.

Assay Number	1	2	3
Weight of Shale Sample	61.80	--------	--------
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	79.62	--------	--------
Weight of Receiving Graduate with Crude Shale Oil Removed	77.14	--------	--------
Weight of Crude Shale Oil Recovered	2.48	--------	--------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35 cc of Crude Shale Oil	0.33	--------	--------
S.G. = $\frac{\text{Weight of 0.35 cc Crude}}{\text{Volume of S.G. Flask (0.35 cc)}}$	0.943	--------	--------
DETERMINATION OF VOLUME RECOVERED			
Volume = $\frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	2.63	--------	--------
DETERMINATION OF YIELD IN GAL/TON			
Yield (gal/ton) = $\frac{\text{Volume(cc)} \times 240}{\text{Weight of Sample}}$	10.02	--------	--------
DETERMINATION OF AVERAGE YIELD			
Average Yield = $\frac{\text{Sum of Assays}}{\text{Number of Assays}}$	10.00 gallons/ton		

APPENDIX F

OIL SHALE ASSAY RECORD

31? see p. 28

SHALE: Basal Paine shale, basal Lodgepole formation

LOCATION: Crystal Lake Road, section 35, T. 12 N., R. 18 E.

Assay Number	1	2	3
Weight of Shale Sample	78.66	77.43	-------
DETERMINATION OF WEIGHT OF CRUDE OIL			
Weight of Receiving Graduate and Distillate	63.96	64.83	--------
Weight of Receiving Graduate with Crude Shale Oil Removed	63.46	64.40	-------
Weight of Crude Shale Oil Recovered	0.50	0.43	--------
DETERMINATION OF SPECIFIC GRAVITY			
Weight of 0.35cc of Crude Shale Oil	0.35	0.35	--------
S.G. = $\frac{\text{Weight of 0.35cc of Crude}}{\text{Volume of S.G. Flask (0.35 cc)}}$	1.0	1.0	--------
DETERMINATION OF VOLUME RECOVERED			
Volume = $\frac{\text{Weight of Crude Recovered}}{\text{S.G. of Crude Oil Recovered}}$	0.50	0.43	--------
DETERMINATION OF YIELD IN GAL/TON			
Yield (gal/ton) = $\frac{\text{Volume(cc) X 240}}{\text{Weight of Sample}}$	1.53	1.34	--------
DETERMINATION OF AVERAGE YIELD			
Average Yield = $\frac{\text{Sum of Assays}}{\text{Number of Assays}}$	1.43 gallons/ton		

APPENDIX G